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## The Case for a Unified Linear Reference System

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# **The Case for a Unified Linear Reference System**

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*Abstract Follows*

## Abstract

The transportation industry distinguishes its activities and data into three functionally and institutionally distinct domains. Transportation infrastructure management activities make transport links (e.g., roads, rail lines, transit routes) available for travel. In contrast, civilian and military transport operations focus on finding and using the best transport links. Each of these three transportation interest groups – transportation facility operators, civilian and military transportation users – currently collects and maintains separate, often redundant or inconsistent information concerning the location and status of the transportation system, the vehicles using the system, and the passengers and freight (or materiel) being conveyed.

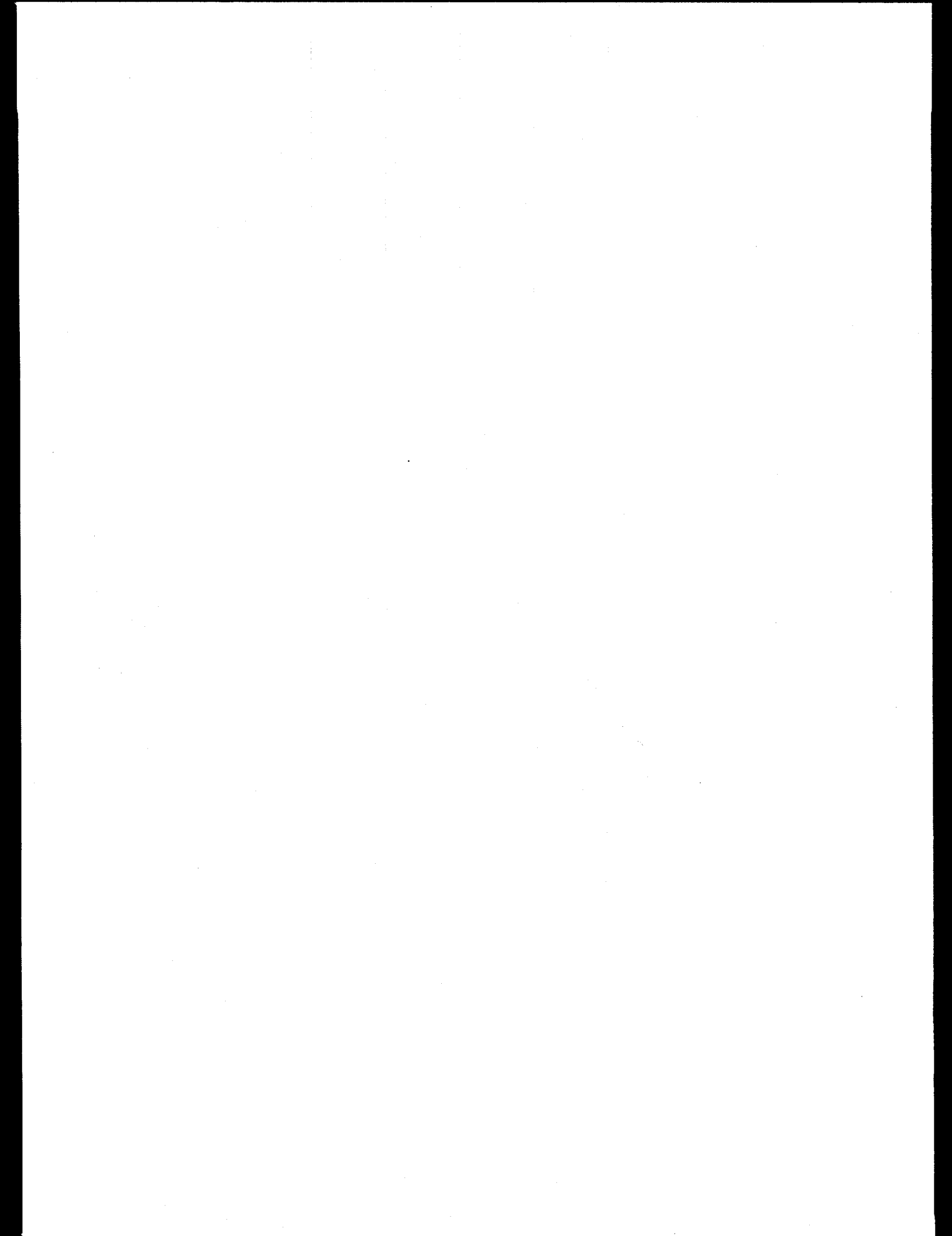
Although there has been some progress made in integrating data within each domain, little emphasis has been placed on identifying and improving the flow of information between them. Because activities initiated in one domain affect conditions in the others, defining these flows is crucial to the next generation of planners, traffic managers and customers of transportation services. For example, construction and maintenance activities affect civilian and military route choices and travel times; large scale military movements disrupt civilian travel and have potentially major effects on the infrastructure and so on. This intertwined interest in the transportation system implies the need for data integration not only within each sphere of interest but among the spheres as well. Although recent policy statements by the U.S. Departments of Transportation and Defense and ITS America indicate a desire to combine and share information resources, there are enormous technical and institutional barriers that need to be overcome.

Over the past decade, information analysts in all three domains have independently concluded that location is a primary information need and a central information integration strategy. Knowing where components and events are relative to one another is essential for planning and operational decision-making. Additionally, these locations serve as a significant integrating mechanism when used as the basis for the organization of information and the design of information systems such as GIS-T. Consequently, there has been considerable work done independently in all three domains to define various location reference methods and standards. However, until now there has been no attempt to define a unified approach applicable across all three domains.

Recognizing that there was both a fair degree of overlap among these independent efforts and an opportunity to establish a single location control framework encompassing all three domains, representatives from each domain met to explore such an option. After a day and a half of technical discussions those representatives, along with several invited location experts, concluded that the location control needs of public sector, civilian and military transportation planning and operational activities can be satisfied by a single, comprehensive technical and institutional approach led by the Federal Government and supplemented by state and local transportation efforts.

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In addition to this overall finding, the attendees identified several factors impeding the adoption of a single transportation location control strategy, developed preliminary sets of user and technical specifications for a unified approach, identified a research agenda addressing certain technical implications of the specifications and finally generated institutional recommendations for moving forward. This paper is a report of those findings.

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# **The Case for a Unified Linear Reference System**

## **1. INTRODUCTION**

The transportation industry distinguishes its activities and data into three functionally and institutionally distinct domains. Transportation infrastructure management activities make transport links (e.g., roads, rail lines, transit routes) available for travel. In contrast, civilian and military transport operations focus on finding and using the best transport links. Each of these three transportation interest groups – transportation facility operators, civilian and military transportation users – currently collects and maintains separate, often redundant or inconsistent information concerning the location and status of the transportation system, the vehicles using the system and the passengers and freight (or materiel) being conveyed.

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Recognizing that there was both a fair degree of overlap among these independent efforts and an opportunity to establish a single location control framework encompassing all three domains, representatives from each domain met to explore such an option<sup>1</sup>. After a day and a half of technical discussions those representatives, along with several invited location

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<sup>1</sup> The workshop was held in Madison, Wisconsin on May 10–11, 1996.

experts, concluded that the location control needs of public sector, civilian, and military transportation planning and operational activities can be satisfied by a single, comprehensive technical and institutional approach led by the Federal Government and supplemented by state and local transportation efforts.

In addition to this overall finding, the attendees identified several factors impeding the adoption of a single transportation location control strategy, developed preliminary sets of user and technical specifications for a unified approach, identified a research agenda addressing certain technical implications of the specifications and finally generated institutional recommendations for moving forward. This paper is a report of those findings.

## 2. WHAT IS A UNIFIED LINEAR DATUM?

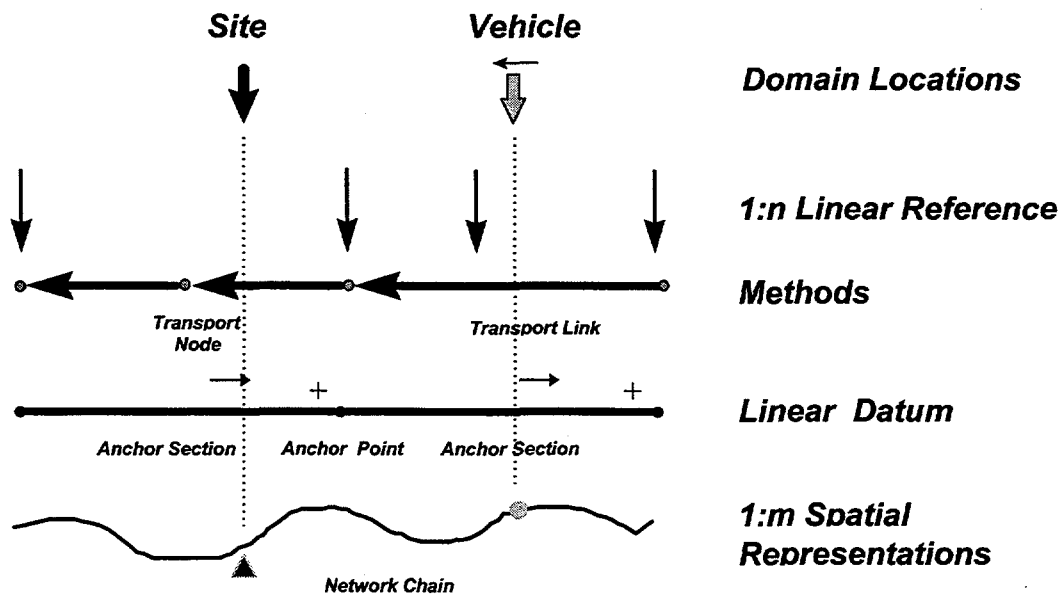


Figure 1: Schematic view of the Linear Reference System

The linear datum as defined by the NCHRP generic data model for linear referencing systems is:

“... the collection of objects which serve as the basis for locating the linear referencing system in the real world. The datum relates the data base representation to the real world and provides the domain for transformations among linear referencing systems and among geographic representations. The datum consists of a connected set of anchor sections that have anchor points at their junctions and termini. No (application) attributes are assigned to the datum [2].”

A unified linear datum encompasses national, statewide and local transportation facilities and is used as control for infrastructure, vehicle and container locations. The significant point is that the same datum (*i.e.*, anchor points and anchor sections) underlies and is used by public sector transportation managers, the ITS community and the military. This common structure will provide for the unambiguous transfer of location based data both within and among these groups. It should be noted that not all applications will require every component contained in the datum. Only that there be one and only one component (*i.e.*, one with a unique identifier) that controls a specific fragment of the transportation system. This component then controls those locations that fall within its linear extent.

The control framework is NOT a transport systems application network. That is, it does NOT include any transport systems flow topology or application data (*e.g.*, capacity, demand, or impedance characteristics). Routes, junctions, intersections, terminals, travel links, and other domain specific object classes are tied to the datum; they are not parts of it. The procedures for determining the locations and extents of the datum components are based on control surveying principles, not on transport logic<sup>2</sup>.

### 3. ISSUES IMPEDING LINEAR DATUM UNIFICATION

Several issues were seen to be hindering the progress toward a unified surface transportation location strategy. These were a combination of conceptual, semantic, technical, and operational factors. Each of these must be successfully overcome before true unification can take place.

- 1) There is considerable confusion over the distinctions between field, map and data base "location" concepts. Field data collectors generally view locations as measurements referenced to an arbitrary number of known reference objects. Map makers and users view locations as coordinates referenced to some planar origin. Data base designers view locations as data indexing mechanisms. Each camp has a variety of measurement systems (*e.g.*, state plane coordinate systems) available to them with some overlap of systems. However tempting it may be to use the same objects in each domain, the contextual differences among the field, map and data base imply separate considerations, integrity rules, associations and so on. Field positions, map locations and data base addresses are NOT the same attributes and will not generally have the same coordinate values<sup>3</sup>. Many transportation agencies attempted to use field locations or map positions as data base keys. This strategy was difficult to maintain over time because of the dynamic nature of the field locations (*e.g.*, changes in route designations and changes in mile point values resulting from realignments). A smaller number were equally unsuccessful in their attempts to use data base keys as field locations.

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<sup>2</sup> The University of Wisconsin-Madison has developed a set of draft datum design guidelines under SNL Contract AT-4567, "A Methodology for Design of a Linear Referencing System for Surface Transportation."

<sup>3</sup> The differences are related to the precision, accuracy, and resolution of the data.

- 2) Over the past few years there have been several national efforts aimed at producing a standard non-proprietary model specification for linear reference [1,2,3]. However, at this time there is still a lack of "universal" consensus about these specifications. The concept of a completely application and view independent linear datum, used only to control the relative locations of linear objects and events, is poorly understood at this time.
- 3) Even though the first linear reference software appeared more than 20 years ago, there is still a lack of technical support (*i.e.*, products and services) of linear referenced location data. Most software is still *ad hoc* and idiosyncratic. Most of these proprietary approaches have sacrificed conceptual rigor for application specific performance enhancement. To the best of the authors' knowledge, only a few commercially available software systems can support the requirements laid out in the cited references.
- 4) Given the lack of a standard specification and the subsequent lack of supporting technology, the final impedance to a unified approach is the lack of operational experience with developing and managing large control frameworks. There is not enough 'real world' experience to convince any but the most risk tolerant to abandon their current efforts and adopt a new strategy.

#### 4. PROPOSITIONS CONCERNING THE UNIFIED LINEAR DATUM

Dimension	Datum Name	Datum Object	Reference Object	Location Specification	Custodian
3-D	WGS84	3-D Cartesian axes, origin at earth's center of mass	Satellite constellation	X, Y, Z	DOD
2-D (Horizontal)	NAD83	Ellipsoid	Horizontal control station	$\phi, \lambda$	NGS/States
2-D (non-mathematical)	PLSS	Section Corner	Monument	Town, Range, Section, part	BLM/ Counties
1-D (Vertical)	NAVD88	Geoid	Benchmark	elevation	NGS/States
1-D (Linear) proposed	linear reference datum	Anchor section, Anchor point	Traversal reference point (TRP)	TRP + offset	DOT/States

TABLE 1. Comparison of Datum Characteristics<sup>4</sup>

<sup>4</sup> This Table was adopted from Vonderohe, *et. al.*, "A Methodology for Design of a Linear Referencing System for Surface Transportation."

The case for a unified linear datum starts with the following propositions. These propositions outline the basic technical and institutional architecture for the datum.

- 1) The need for national (and international) surface transportation location control is very similar to the need for geographic horizontal and vertical control. Historically, horizontal and vertical control were established initially for charting in support of navigation. The proposed linear datum is similarly justified as necessary for navigation [1]. Additionally, as Table 1 illustrates, the proposed structure of the linear datum is analogous to other established datums.
- 2) Federal custodianship of national datum objects referenced for navigational uses has precedence as shown in Table 1. Custodianship implies establishment of a national datum plus policies and recommended procedures for expanding the datum for local purposes. It should be noted that each of the existing datums with Federal oversight was created by congressional mandate. No such mandate for land surface transportation currently exists.
- 3) Surface transportation location control is multi-modal and multi-jurisdictional and controls regions of varying extents (*e.g.*, international, national, corridor, statewide regional, municipal). State and local jurisdictions will add linear datum objects to the national framework (*i.e.*, densify the network). This proposition is consistent with the way in which control points are managed in the horizontal and vertical datums.
- 4) Linear datum objects can and should be tied to at least the WGS84 3-D datum. Tying the linear datum to a mathematical datum provides the same benefits as tying the Public Land Survey System to a mathematical datum (*e.g.*, reference object recovery, mapping, data fusion).

## 5. UNIVERSAL DATUM SPECIFICATIONS

The following specifications were identified as a set of (incomplete) requirements for a unified linear datum. These specifications represent the datum users' expectations.

- 1) The purpose of the datum is to transform locations between the real world space and data world space(s) and to project positions between data spaces.
- 2) The datum needs to be a consistent, nationwide framework accessible to public and private customers.
- 3) The datum will be used in multiple public domain and proprietary data bases.
- 4) Although the datum itself must be in the public domain, many applications using this framework will be proprietary.
- 5) The datum needs to be able to control location at multiple levels of resolution (*e.g.*, highway location, roadway location, lane location).
- 6) The datum needs to be able to control locations determined by many different methods.
- 7) Each functional domain has distinctly different accuracy specifications. This is a function of either the smallest objects (*i.e.*, the highest resolution) in the domain(s), the need to

discriminate the relative distance between two objects or the precision of the location measurement devices.

- 8) Navigation and traveler information functions need 3–5 meter positional accuracy. This may be derived from the need to discriminate individual vehicles.
- 9) Field location datum objects and reference objects need to be identified easily in the field. These objects also need to be fixed, stable and recoverable over long periods of time (decades, if not longer).
- 10) The unified datum should be domain content (*i.e.*, application) neutral.

## 6. DESIGN SPECIFICATIONS

The following specifications represent considerations of interest to datum designers.

- 1) Complex interchanges may be controlled with a combination of absolute and relative points.
- 2) Real time location signatures must live within severe data transfer bandwidth constraints.
- 3) Travel (*i.e.*, transport) links do not need to be coincident with location control links (*i.e.*, anchor sections).
- 4) Higher object resolutions may require more communication bandwidth. Greater data precision may also exceed available communication bandwidths.
- 5) Anchor sections have only directional and control distance attributes. They do not have shape attributes. Sections can be associated with shape points (*i.e.*, chains) if necessary for display purposes.
- 6) Anchor section distance (*i.e.*, control distance) may be determined from repeated field measurements (*i.e.*, the statistical mean distance), by design distance (*i.e.*, COGO reference line lengths) or can be defined arbitrarily (*e.g.*, equivalent to local road aid mileage).
- 7) Field location reference objects need not be the same as datum objects. The same real world feature (*e.g.*, an at-grade intersection) may have a number of roles and be represented in the data base by multiple objects (*e.g.*, a node, an anchor point, a traversal reference point).
- 8) The linear datum can be expanded over time to accommodate new surface transportation facilities. The datum can also be expanded to control facilities not originally included.
- 9) Additional design specifications are determined by existing and proposed applications. The design must be flexible enough to accommodate as yet unidentified applications. At the same time the design should not introduce any application biases (*e.g.*, cost, performance).

## 7. RESEARCH QUESTIONS

Many questions must be answered before the unified datum can become a reality. The participants identified the following issues as essential. These questions are being addressed by a SNL/ UW-Madison joint research project on linear datums.

- 1) What is the relationship between the density of linear control points and their associated quality (*i.e.*, accuracy, precision, resolution)?
- 2) How dense should the reference network be? (asked another way, how long should the anchor sections be?)
- 3) How are anchor points identified (*e.g.*, monuments, features, coordinates)? What happens to an anchor point whose associated feature has been moved?
- 4) What transportation locations make good anchor points? One possibility is to locate them at construction project termini.
- 5) What are the advantages/disadvantages of using project reference lines or center lines as anchor sections?
- 6) Are the accuracy requirements for the three functional domains identical? What should the precision of the anchor section distance values be?
- 7) Is the reference network located on the earth's surface, on the ellipsoid, in 3-space, somewhere else?
- 8) How are transport nodes assigned to anchor sections? Can there be ambiguity or uncertainty in the assignment?
- 9) How should the reference network be operationalized?
- 10) Is the linear datum relationship between extent and accuracy different than that relationship for geodetic datums?
- 11) Should accuracy requirements be expressed in relative or absolute terms?

## 8. RECOMMENDATIONS

In order for the unified linear datum to exist, it needs an institutional context. The participants agreed that the overwhelming use of the unified approach will be for ITS applications. As a result, it makes sense that the datum be established and supported by this initiative. The following recommendations are based on that assumption.

- 1) Synthesize a single domain model for surface transportation location reference incorporating multiple location reference methods from the three existing separate domain models. Based on the participants' knowledge, this synthesis is more likely to involve adopting a consistent set of terms and definitions to describe identical concepts as opposed to having to reconcile divergent ideas.
- 2) Incorporate this specification into the ITS Linear Reference Standard.

- 3) Extend the FGDC Geospatial Positioning Accuracy Standards to include linearly referenced points.
- 4) Develop a joint policies and procedures standard for establishing national, statewide, and local datums.

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Bruce Spear, U.S. DOT Bureau of Transportation Statistics

Alan Vonderohe, University of Wisconsin - Madison

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- 3) Fletcher, D., Henderson, T., and J. Espinoza; "GIS-T/ISTEA Management Systems Server-Net Prototype Pooled Fund Study Systems Analysis and Preliminary Design;" Albuquerque NM, 1995.

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